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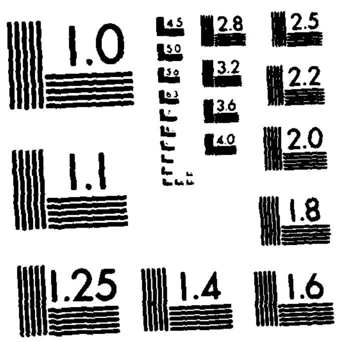

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AVIONICS INTEGRITY PROGRAM (AVIP) - VOLUME II

Hardware Case Studies

BATTELLE MEMORIAL INSTITUTE
COLUMBUS LABORATORIES
COLUMBUS, OHIO 43201

Ellis F. Hitt

Donald Eldridge

MARCH 1984

TECHNICAL REPORT ASD-TR-84-5011
Final Report for Period September 1983 to March 1984

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AERONAUTICAL SYSTEMS DIVISION
AVIONICS INTEGRITY PROGRAM OFFICE
DIRECTORATE OF AVIONICS ENGINEERING
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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The report presents a review of the efforts that several avionic manufacturers and systems integrators are using to eliminate defective parts and processes in hardware prior to delivery to a procuring activity. Time phasing for the major efforts vary among manufacturers depending on what is perceived to be best within their own realm of manufacturing operations. The resultant data identified areas of concern especially (a) feedback from the field on the nature and types of errors that are being encountered, (b) the utility of built-in=test/fault-isolation-test, and (c) the specific nature and utilization of test equipment and establishment of data base information obtained from the test equipment. The case studies should be expanded to include data from the various users as well as from the base or depot level repair stations. The data from these organizations, if properly used, could improve the integrity of the product, especially for the next generation avionics systems.

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VOLUME II: CASE STUDIES

TABLE OF CONTENTS

LIST OF TABLES

Page

FOREWORD

This report is one of a series of four prepared for the Avionics Integrity Program Office, Wright-Patterson Air Force Base, Ohio. The reports address techniques and historical data (lessons learned) for enhancing the service life of avionic systems. The reports include contractor efforts between September 1983 and March 1984.

Each report represents a completed study in a specific area and stands alone. However, the contents of the four reports are meant to complement each other and they should be considered as the output of a single study aimed at determining those issues which contribute to the avionics integrity of military systems.

The titles of the remaining reports and their respective technical report numbers are provided as follows:

> ASD-TR-84-5009, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Program Cost Assessment - Environmental Stress Screening and Diagnostic Techniques, Volume III
>
> ASD-TR-84-5010, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Volume I, Procurement Phase Issues - Design, Manufacturing, and Integration
>
> ASD-TR-84-5012, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Force Management - Economic Life Considerations, Volume IV

These reports have been entered into the DTIC/NTIS system. Contact the Avionics Integrity Program focal point ((513)255-3369) to obtain the appropriate report number for ordering.

The authors wish to acknowledge the cooperation and consideration afforded to them by Mr. Thomas Dickman, Mr. John Kaufhold, and Major Lee Cheshire of the Avionics Integrity Program Office during the conduct of these studies. Without their continuing guidance and interest, these reports could not have been developed. The authors would also like to thank Mr. Tom Dolash, Mr. Keith Broerman, Susan Hendershot, Nanci Peterson, and the Text Processing Center personnel at Battelle Columbus Laboratories for their contribution to these reports.

1.0 INTRODUCTION

Case studies were conducted on two specific avionics processors, the Delco 362F and the IBM AP-101C, and two avionics systems which utilize these processors, the F-16 and B-52 Offensive Avionics System (OAS), respectively.

The objectives of these case studies were to:

(1) Collect information and data from the computer manufacturers and the avionics system integrators with respect to their product and the integrity issues associated with that product.

(2) Analyze the information and data collected to develop an evaluation of the relative merit of each design, manufacturing, and integration approach method for specific integrity related activities.

(3) Identify problems encountered by the manufacturers and system integrators in the development of the respective subsystems or systems.

Visits were made by a team of USAF ASD/ENAS/AVIP project personnel and Battelle project personnel to each airborne computer manufacturer's facilities to interview project team members, review and observe design and manufacturing methods, procedures and processes, and to collect data with respect to these issues.

The system integrators were visited, by the same team, to collect similar information.

The resultant data were then analyzed in terms of identified activities, sub-activities, methodologies, tools and their impact on the various integrity attributes.

1.1 AIRBORNE COMPUTER DESIGN/MANUFACTURING

Both of the computers studied were derivatives of earlier designs. As a result, the machines did not make use of the newest technology available. Both manufacturers used core memory with parity (as required by the specifications developed for procurement of the computer).

A synopsis of the findings of the case studies on the computers follows.

1.1.1 F-16 Fire Control Computer

The F-16 Fire Control Computer (FCC) is a product of the Delco Systems Operation, General Motors Corporation. The FCC version used in the F-16 is the Delco 362F, a member of the Delco Magic computer family.

1.1.1.1 Design

The design of the Delco computer was a derivative of earlier Delco computer designs. The history of the 362F began with the 301 used in the Short Range Attack Missile (SRAM), the 311 used in the Delco Carousel IV inertial navigation system, the 352 used in the Titan and Delta launch vehicles' inertial guidance systems, and the 362 used in the Navy ATIGS.

The 362F design was performed using primarily manual methods. (Delco prefers to convince the customer that they can meet the customer's requirements with an existing machine with as few design and manufacturing changes as possible. Delco then modifies the design to meet the environment.)

In the case of the 362F, General Dynamics was the intermediate customer with the USAF the final customer. General Dynamics wrote the specifications in response to USAF requirements. General Dynamics specified use of core memory and floating point arithmetic.

The computer architecture and instruction set were designed by Delco. After the input/output (I/O) and other functions were defined, the Delco design approach moved to parts selection.

Delco parts selection methods differentiate between whether the item is a prototype item or a production item. Parts derating makes use of Delco procedures which are more stringent than military derating procedures. Every part has to be approved by the Delco parts engineering group prior to release from design. Every parameter of every part must be verified.

Thermal analysis is performed using a nodal model. Estimated thermal deltas are mapped into junction temperatures. (When a physical machine is available, it is instrumented by the same person who did the thermal analysis, to collect thermal data to validate the design analysis.)

Delco does not use a mathematical model for vibration analysis. Random and sinusoidal vibration is used by Delco in design verification and in qualification testing. Delco personnel stated that sinusoidal vibration by itself is not useful for test screening.

Every part must be electrically, thermally, and environmentally acceptable. Delco uses MIL-M-38510 qualified parts if they are available. All parts are subjected to three temperature tests (high, low, and ambient) with power applied to the parts. After experience is gained with a part, Delco either samples parts in a lot, or uses a single temperature screen on 100 percent of the parts. For a number of parts, Delco uses three point temperature tests rather than the temperature cycle since they feel a cycle is too expensive. Delco also performs a destructive test and a life test on the parts.

Delco's experience is that MIL-M-38510 parts have a higher acceptance rate than the MIL-STD-883B parts. However, Delco also stated that vendors want to get out of supplying MIL-M-38510 parts. Delco has an acceptable supplier list (ASL) and also uses MIL-qualified parts lists. Delco requires their ASL to perform 100 percent test and burn-in to MIL-STD-883B on 100 percent of the parts Delco buys.

Delco stated that DESC allowed vendors to make Class I changes to get more qualified suppliers without changing the part number. As a result, Delco first screens the part to the military requirements and then to the more severe Delco requirements.

Delco uses the LASAR program of Teradyne for testability analysis. Logic simulation programs such as LASAR are required by General Dynamics. Delco personnel did not know whether USAF required the use of that program.

General Dynamics required 95 percent fault detection and 95 percent fault isolation. Delco negotiated with General Dynamics a full scale development goal of 90 percent with growth to 97 percent. In order to meet the testability requirements, they must be considered early in the design stage. This benefits Delco at the card level testing. Any logic change necessitates rerun of the LASAR program.

Incorporation of built-in test and fault isolation necessitated redesign of test equipment used by Delco.

Component placement is done on new Delco designs using computer assisted design. Delco uses the General Electric Calma for layout. The components are placed using x,y coordinates to locate the integrated circuits and other discrete components on the board.

1.1.1.2 Manufacturing

Upon completion of the board layout, the parts list and placement of parts are transmitted by computer to the layout computer at Delco's Milwaukee manufacturing facility. This facility does the physical fabrication of the boards. Delco performs a complete inspection and environmental test program on each board. The failures are documented in a formal failure reporting system. Each failure is entered into a data bank and after the appropriate design change has been developed, it too is entered into the data bank indicating what was fixed.

The cards are returned to the Goleta facility and assembled into the LRU box. The pre-production program used a card extender with a thermal hood. This configuration is subjected to environmental stress screening tests. An environmental test program is loaded into the computer and run while in the chamber.

The F-16 environmental stress screening (ESS) tests were based on thermal inertia and involved a -60°C cold soak followed by a turn-on and run for 6 hours at -40°C followed by cycle 2 ambient and then hot soak and turn-on. Delco performed eight ESS cycles for the F-16 program.

Ten cycles were used for the MADAR for the C-5B. The last 4 cycles must be failure free. After completing the above sequence, one cycle, which includes random vibration, is run for acceptance tests. Delco will not use less than 8 ESS cycles.

Delco stated that the LANTIRN program required vibration on every cycle. Delco does not think that vibration helps screen. The combined vibration and temperature does not help screen. Delco runs a random vibration test at one temperature on the boards. The type of ESS test and qualification test are dependent on the environment.

The production program cards are tested using a hot, ambient, cold, ambient powered program with the temperatures 5° lower and 10° higher than the box level test. Thermal shock is not part of the acceptance test.

The predicted reliability of the Delco 362F is between 2100 and 2200 hours. The mean-time-between-repair is over 2500 hours. Delco stated that, according to General Dynamics, the mean-time-between-removal is much less, on the order of 600 to 700 hours.

The reliability calculations were performed by Delco, using MIL-HDBK-217D in response to the RFP. Delco then modified the data using the data base prior to the preliminary design review (PDR) and critical design review (CDR). Delco stated that every bidder must use MIL-HDBK-217D to be responsive to the RFP. Delco, as previously stated, used its own derating criteria.

Each program at Delco has a reliability manager and all reliability managers report to a system effectiveness manager. The quality control/assurance manager reports to the plant manager. Delco has one quality standard but each program has its own reliability standard.

1.1.1.3 Operations/Maintenance

Delco stated that they do not receive a great deal of feedback from USAF or General Dynamics on the operational experience with the 362F. Delco stated that every software error causes the computer to be pulled. The only software in the machine that Delco developed is the operational self-test software. General Dynamics developed the rest of the software. Delco stated that a lot of false pulls are due to software which results in cannot duplicate (CND) condition. Delco does not get that data. It was suggested by Delco that USAF feedback to the manufacturer data from each pull, including when it was pulled and why it was pulled.

The latest version of the 362F, D^3, has had the elapsed time indicator removed. There is no record of on (operating) time or flight time on these computers. Delco does not think this is a good policy.

Delco has been performing the repair on the 362F computer. The USAF is just starting to make the transition to organic maintenance for the 362F. Delco is concerned that they will get no feedback information once the transition to organic maintenance is completed. In order to apply lessons learned to the next generation computer, it is important that both the user and the organization performing the maintenance feedback information to the manufacturer of the computer. Computerized data bases containing this information will be of great value to both the manufacturer and the USAF in the design and manufacture of next generation computers. This may be the only form of corporate memory that will be of significant use in future designs since, as in the case of Delco, the original design team personnel have moved to other projects or retired.

1.1.2 B-52 Offensive Avionics System (OAS) Computer

The B-52 Offensive Avionics System Computer is a product of the IBM Federal Systems Division. The computer used in the B-52 OAS is the AP-101C, a member of the Advanced System/4 Pi Modular Computer Series.

1.1.2.1 Design

The design of the AP-101C computer was a derivative of earlier IBM computer designs. The history of the AP-101C began with the model AP-1 used in the F-15. The AP-1 was a fixed point, hard wired control machine using modular core memory. This was followed by the AP-101B used in the NASA F-8 digital fly-by-wire program and the space shuttle orbiter. The AP-101B is a floating point machine using microprogrammed control.

The AP-101B is used in the B-52 digital bomb navigation system and the B-52G/H Offensive Avionics System.

The central processing unit (CPU) for the AP-101C was a new design. The memory was not. IBM does not use any design or logic checking program like the TEGAS 5.

A list of approved digital parts that have been characterized at the Manassas, Virginia facility must be used by a designer unless that part had been approved because it is so new. The new part must be characterized before it can be used. Manassas's personnel look ahead to see if a part is becoming obsolete and characterize a proposed replacement. Manassas also identifies second sources.

The schematic layout of a board is done using a computer-aided design (CAD) system.

IBM uses a thermal analysis program that computes the heat load, junction temperatures, etc. The CAD may be used to adjust the design as a result of the thermal analyses. The thermal analyses include power dissipation considerations and cooling.

IBM uses IBM derating factors in calculation of the projected reliability. IBM can use MIL-HDBK-217D but the system will not meet the reliability requirements. IBM states they usually have to convince customers that IBM failure rates are correct and they can meet the requirements.

IBM uses qualification levels to screen parts. IBM suggested that USAF describe the actual environment the computer must operate in rather than calling out MIL-E-5400, Class 2. IBM stated that qualification test levels are not necessarily the proper level for incoming parts screening. IBM requires their vendors to perform 100 percent screening to at least MIL-M-38510. IBM then samples and does destructive physical analysis. They perform 100 temperature cycles rather than the ten required per MIL-M-38510. (IBM has been accused of wearing parts out.) IBM stated that they do not pay their suppliers' overhead that a MIL-M-38510 approved supplier charged.

1.1.2.2 Manufacturing

Upon completion of the part selection and board layout, IBM manufactures circuit boards which are glass epoxy multi-layer boards with five or six layers and power and ground layers. IBM uses dual inline packages (DIPS) inserted automatically plus surface mounted devices. Wave soldering and flow soldering are used for most of the soldering. Manual soldering is used for the most difficult soldering. DIPS and discrete components are mounted through the board while flat packs are surface mounted. IBM puts the flat pack on a POGO. The operator tweeks the alignment and then it is automatically soldered. The multi-layer board manufacturing is completely automated. IBM uses low ("zero") insertion force connectors with seven or eight bristles per pin.

Subassembly tests in the factory involve plugging the multi-layer board into a tester which has 200 different programs. Technicians select the correct test program which is semi-automated. Any identified failure is fixed. The board is then retested. The board is visually inspected and a conformal coating applied, followed by another visual inspection. The board is then put into stock.

The AP-101C chassis comes assembled. Shop replaceable units (SRUs) are removed from stock and a unit is assembled with SRUs pulled from stock.

The unit is subjected to ten cycles of temperature and then a single axis random vibration along the board is performed. The factory test program is then run. IBM then reruns the ten thermal cycles followed by random vibration. The unit is taken up to 71°C (upper temperature) with cooling air applied. This takes about 30 minutes. The unit is then taken down to -54°C for the lowest temperature. The unit is cold soaked and then cold started and run with the factory test program. IBM then runs the temperature to 71°C and operates the unit for 6-1/2 hours with power on. IBM still sees hard failures at the final box level test even though they test each SRU and screen the parts before assembling them into an SRU.

IBM takes the unit out of factory burn-in and puts the unit into a customer specified burn-in. After completion of that test, the units are painted and the customer acceptance test is performed at room temperature. IBM allows eight weeks for final testing prior to customer acceptance.

IBM believes test, analyze, and fix (TAF) needs to start as early as possible. The problem with this approach is the competition for a limited amount of test equipment. There have been approximately 200 to 300 design changes made since 1978. Approximately 60 percent of these changes are logic design changes and approximately 40 percent are manufacturing changes. A PROM change is currently underway.

The audit trail is performed manually for the B-52 OAS program. IBM loses track of "what serial number page is in what unit" once it leaves IBM. The as-built list is on the facility computer system at IBM. An automated data collection system which tracks where each SRU is would be useful. The lot number and day code indicate the pages built from this date and other dates. IBM does an individual inspection on a recall to check if it has a day code on a bad chip.

The AP-101C drawings are on paper and were done manually. The B-1B computer was designed using CAD and the drawing information is stored on the computer.

1.1.2.3 Operations/Maintenance

IBM did not have responsibility for the avionics system software. IBM provided part of the original built-in test (BIT) software to Boeing who then wrote the BIT software and the operational flight program (OFP). The United States Air Force intermediate level tester is a Boeing 479 tester. If Boeing or the USAF personnel cannot find the trouble using the intermediate level tester, the machine is sent to IBM. IBM receives very little information on the reasons for removal of the processor. If Boeing finds a faulty SRU, they replace that "page". All failed pages or SRUs are repaired by IBM. Boeing/USAF does not do "page" repair.

Since IBM does not receive information for the reason for removal of the units, more money is spent on trying to find troubles that retest OK than in the case of an obviously faulty unit.

The demonstrated mean-time-between-failure (MTBF) of the AP-101C is approximately 1600 hours whereas the specification was 1800 hours. The mean-time-between-removal is approximately 600 to 800 hours. About half of the removals retest OK. IBM stated that in general, comparing the specification data and the field data is like comparing apples to oranges. The aircraft time is the flight time, while the total time on the elapsed time indicator on the AP-101C is the ground plus flight time.

The most difficult software problems are showing up two to four years downstream after introduction of a processor. The manufacturer needs data on the problem and environment at that time. The USAF Boeing-provided tester reloads data on power-up; therefore, it is not possible for IBM to get a memory dump from the processor which has failed unless the machine is sent directly to IBM where they use their own tester. IBM believes that companies must be involved in the field engineering support and doing the failure analysis and reporting.

IBM stressed the need to spend more time in the Concept Definition Study phase, especially for a major procurement. IBM estimated that it would take approximately one year to do the job properly. In addition, IBM stressed the need to complete all of the evaluation studies very early in the design process. In the case of the AP-101C, IBM had only four to six weeks to conduct the Concept Definition Study.

IBM stressed that technology infusion does not work unless it is part of pre-planned product improvement. The AP-101C use of core memory is an example. The core memory is no longer being manufactured by the IBM supplier. IBM has stockpiled core memory, but once it runs out of the stockpile, a new "page" will have to be designed to meet the old (present) interface.

In 1978, IBM committed to prices through 1985. Hardware costs can be passed through. The hardware costs have decreased over time.

IBM would like to see the USAF implement a system which would allow them to collect data on each failure so that they might make use of this historical information in design of the next generation of computers. Implementation of such a system would require user involvement as well as the various Air Force Logistics Command (AFLC) maintenance organizations.

1.2 AVIONICS SYSTEM INTEGRATION

The system integrators using the Delco 362F and IBM AP-101C were visited after the completion of the computer case studies. These integrators were General Dynamics, Fort Worth, Texas (Delco 362F) and Boeing Military Aircraft, Wichita, Kansas (IBM AP-101C).

1.2.1 F-16 Avionics System Integration

The F-16 was a new aircraft for which the Avionics System was designed by General Dynamics, Forth Worth, Texas. The Avionics System itself was comprised of Government Furnished Equipment (GFE) and avionics developed specifically for the F-16.

1.2.1.1 Design

General Dynamics established the design requirements for the F-16 Avionics System. The system was designed to perform both the air-to-air and the air-to-ground mission.

The F-16 Avionics System architecture is based upon the use of MIL-STD-1553 multiplex data bus with embedded remote terminals in most of the Line Replaceable Units (LRUs). Some Government Furnished Equipment (GFE) avionics are not interfaced with the multiplex system. Those items not interfaced with the multiplex include the communication, radio navigation, and identification subsystems.

The fire control computer, the Delco Magic 362F, performs all fire control system processing including control of the multiplex data buses, and energy management, air-to-ground attack computation, and air-to-air attack computations.

General Dynamics also designed and manufactured subsystems which interface with multiplex systems including the store's management subsystem.

General Dynamics was given the requirements, by USAF, for the avionics system specifications. The systems integration plan was developed prior to full-scale development. General Dynamics worked with each supplier to make sure they met the interfaces, used the right processes, performed the right tests, etc. Then, as each item was accepted at the supplier's facility, it was shipped to General Dynamics for integration with General Dynamics developed software. The original system integration was performed in the systems integration laboratory prior to full-scale development, or there being an actual aircraft ready for integration of the system.

Each subcontractor runs reliability and maintainability (R&M) tests witnessed by General Dynamics at the sub-contractor's facility using test plans furnished by General Dynamics. General Dynamics also runs R&M test on all General Dynamics manufactured items.

In full-scale development, General Dynamics use MIL-STD-781B reliability test methods including sinusoidal vibration. Qualification testing required random vibration. General Dynamics' reliability qualification test (RQT) was carefully designed since USAF required General Dynamics to perform in production any type of test they performed during RQT. The General Dynamics RQT is not the same as the USAF test, analyze, and fix (TAF). During RQT, random vibration was used only on the radar at Westinghouse. General Dynamics does not think sinusoidal vibration contributes very much towards screening or stress testing. The USAF did not specify or require RQT or burn-in specifically as General Dynamics did it; General Dynamics used their own company procedures. The only burn-in required on the hardware is that necessary to pass RQT.

General Dynamics stated that temperature screens are good only if the equipment is operating. If General Dynamics had to choose between temperature screens and random vibration screens, they would choose a temperature screen.

General Dynamics buys MIL-M-38510 or MIL-STD-883B parts. General Dynamics did not initially do any incoming screening. This resulted in 17 to 20 percent failure on the line. General Dynamics went to an independent laboratory to perform screening, using a high-ambient-low temperature screen and rejected 4,950 out of 5,000 parts. General Dynamics is now screening at the piece part level. General Dynamics feels screening should be optional at the Shop Replaceable Unit (SRU) level. General Dynamics believes that if the manufacture's process (soldering, etc.) is controlled and piece parts are screened, screening is not required at the SRU level.

General Dynamics said that the Defense Electronics Supply Center (DESC) is not making sure that MIL-M-38510 testing is being fully done by manufacturers of components. This necessitates additional effort on the part of manufacturers of sub-systems.

General Dynamics uses MIL-STD-1965, Piece Parts Control and Standardization. General Dynamics has a substitution board that develops a list of alternate, valid parts.

General Dynamics stated that USAF had proposed use of MIL-STD-781C for the reliability testing for the F-16 MSIP.

1.2.1.2 System Integration

The initial integration of the prototype equipment was done in General Dynamics System Integration Laboratory (SIL). Now that the system is in production, integration is performed in the Avionics Intermediate Shop (AIS). FIT tests are done on a continuing basis. AIS engineering tests are also performed on a continuous basis. LRU fault insertion is performed in the Avionics Intermediate Shop at General Dynamics. General Dynamics also has a full-scale mock-up of the avionics equipment bay and cockpit of each of the F-16 models in the systems integration laboratory. This facility is used for software integration tests. Full system integration occurs in Avionics Electronics Bay (AEB) in the systems integration facility.

Design and integration problems are handled using the test, analyze, and fix (TAF) method. General Dynamics said the problem with TAF is that if money is short, a proper fix may not get implemented. General Dynamics does not believe that an RQT should be performed on a total system. While the system is under General Dynamics control, they maintain accurate records on both hardware and software faults. General Dynamic's data base indicates that only approximately 10 percent of avionics faults are software related.

The F-16 Avionics System has implemented sophisticated diagnostic software in the fire control computer. Self-test is continuous during flight and is automatic. The built-in test (BIT) interrupts normal operations, and may be pilot, or ground-maintenance crew initiated. General Dynamics stated that the test BIT gives USAF a better basic product. BIT really impacts design integrity according to General Dynamics. General Dynamics tried to design for 100 percent self-test, but there were a few things that could not be done that made them back down to 95 to 97 percent self-test. The diagnostic software in the fire control computer has no correlation with the software in the Avionics Intermediate Shop (AIS). The General Dynamics developed self-test and built-in test software provides both a pilot's fault list and a maintenance fault list. The maintenance fault list provides a read-out of 388 failure parameters.

Once a system's integration was completed in the system's integration lab, the system was then installed in the flight test aircraft and subjected to full-scale development testing. During that time, General Dynamics provided full support for the system.

1.2.1.3 Operations/Maintenance

The F-16 avionics changes were kept to a minimum from the initial design. Over 1,000 systems have been produced and are in operation.

During the initial operation phase a four year mission-operation, test and evaluation (MOT&E) was conducted with full support from General Dynamics personnel in the field. These personnel were very familiar with the design of the hardware and software of the system. The problems encountered during the MOT&E were fed directly back to General Dynamics for analysis and determination whether an engineering change proposal (ECP) was needed. Many of the problems identified in the field dealt with operator problems as contrasted with hardware and/or software design problems.

Now that General Dynamics personnel are no longer in the field supporting the system, they are not getting feedback of the information they need from the users of the system. The USAF personnel are not filling out the documents according to General Dynamics. General Dynamics receives maintenance fault list (MFL) data only from Nellis AFB, through informal arrangements and not through any consistent contractual obligation or process.

General Dynamics stated that they can obtain information from the organization and the intermediate level maintenance but they can not obtain information from the Depot level. General Dynamics stated that the Depot repair information is not in the AFR 66-1 maintenance data system. General Dynamics tracks the mean-time-between-maintenance actions types 1, 2, and 6.

General Dynamics would like to see the AFR 66-1 system modified to include types 3, 4 and 5 for software faults. Currently there is no way to obtain data on software faults except with a man in the field at every base who has the job to track data. A good engineer on-site can break out failures in terms of hardware, firmware, software, and operator. General Dynamics believes that the maintenance data reporting system must be modified to handle these additional fault categories. In addition, USAF needs to change its procedures to get the user more involved in helping solve some of the maintenance problems as well as the Depot more directly involved in the overall problem.

Once a system reaches maturity, the problems are subtle hardware and software interaction problems such as "race conditions." The only way that these problems can be isolated is through an engineer who knows the system and has available the proper test equipment that will permit the determination of the causes of correlated failures. The current data reporting system does not permit separating the maintenance actions into hard failures versus pilot squawks which are not hard failures. For example, General Dynamics stated that the pilots want as accurate an inertial navigation system as possible when they are being scored during training weapon delivery runs. This often results in the pilot requesting that the inertial navigation system be removed. There are thirteen types of errors on the inertial navigation system and the USAF data system's "HOWMAL" (how malfunction) does not capture all these failures and fault types. As a result the INU is subjected to an extensive test and calibration taking 18 hours. The INS removal operation, even though the unit may be meeting the specifications, is counted as a maintenance action due to the pilot squawk.

General Dynamics is unable to track the shop replaceable units (SRU) once they are delivered to the USAF. USAF personnel remove LRUs and then swap SRUs until they succeed in making the LRU operational. When General Dynamics finally gets an LRU back, all the SRUs in it are bad, in many cases, none of them are the ones that were originally installed in that LRU.

General Dynamics stated that they had difficulty in tracking the LRUs and presented data from one base which indicated that one LRU was removed from an aircraft and subsequently reinstalled in that aircraft. At some later date, that same LRU was removed from another aircraft although there was no record that it had been removed from the previous aircraft and installed in the aircraft that it was subsequently removed from.

General Dynamics cannot provide its suppliers data on SRU faults since General Dynamics does not have that data furnished to it from USAF.

The data provided by USAF is less detailed than that required for today's sophisticated avionics systems which rely heavily upon software. While the avionics system was designed with sophisticated self-test and built-in test, USAF users apparently do not want to provide the maintenance fault information to General Dynamics. General Dynamics had proposed that the maintenance fault list be written to the data transfer unit (DTU) for the F-16 C/D. Maintenance fault list information could then be dumped from the DTU and a hard copy made available to the maintenance personnel. General Dynamics stated that USAF operational personnel did not want the maintenance fault list data written to the DTU, since the DTU also contains mission data such as way-points.

USAF personnel have also directed that the elapsed time indicators be removed from the next batch of Delco computers. USAF told General Dynamics that sparing was based on the flight hours and events, and that they did not intend to use the elapsed time indicators even if the device was on the box. USAF told General Dynamics that the elapsed time indicators themselves were a source of unreliability. Therefore, General Dynamics incentive is now based on mean-time-between-demand not elapsed time on the box.

Better maintenance statistics are required in order to effectively define where software problem areas in an efficient manner. General Dynamics stated that if they cannot duplicate (CND) faults as measured on the aircraft, it does not result in a box being taken out of the aircraft. The statistics that are accumulated on CND include recurring faults being counted multiple times until a box is finally removed. Once a box is removed, if the avionics intermediate shop cannot find anything wrong with it, it is declared as a retest okay (RTOK).

General Dynamics tracks aborts to identify those subsystems contributing to the aborts. General Dynamics then analyzes those subsystems to determine what causes the failure which caused the abort. If corrective action in terms of design or manufacturing processes would solve the problem, General Dynamics prepares an engineering change proposal.

General Dynamics attempts to acquire statistics on the maintenance man/hours spent on specific line or shop replaceable units per maintenance event. As a result of accumulating this type of information by base, General Dynamics determined that 3 out of 4 bases were charging time for training of maintenance personnel to actual maintenance time. This type of data is useful since incorrect time accounting can significantly impact the decision as to whether a design change is required to reduce the maintenance time.

General Dynamics data indicates that the F-16 Avionics System is fairly reliable. They currently get one failure parameter from the maintenance fault list per 10 sorties. The cost of failure is another thing. Avionics maintenance cost is high even though the failure rate is low. General Dynamics feels that these costs can only be reduced through the introduction of improved methods for accumulating field information and identification of problem areas sooner than they are currently identified. In addition, the continued use of Government Furnished Equipment, which is much less reliable than new equipment using current technology, results in significant cost and impact on operational readiness.

General Dynamics does not believe that USAF should stock-pile parts which then would be used for the remaining useful life of the system. General Dynamics believe that parts deteriorate in storage. They believe a substitute part should be used if a part is no longer available. This requires approval for the use of substitute parts. General Dynamics uses a parts substitution board which provides a list of parts that may be substituted for parts no longer available.

General Dynamics stated that better data collection and feedback is needed from the USAF in order to develop and maintain avionics system in a cost-effective manner. Both depot level maintenance procedures as well as user procedures would require modification in order to provide this feedback. General Dynamics believes that as the USAF proceed to two-level maintenance (i.e., the elimination of the intermediate level maintenance), the USAF will have to develop improved management procedures in order to maintain today's and tomorrow's complex avionics systems.

1.2.2 B-52 Offensive Avionics System (OAS) Integration

The B-52 G/H models are being retrofitted with a new offensive avionics system. This system is being integrated by the Boeing Military Airplane Company in Wichita, Kansas, and makes use of the IBM AP-101C Computer.

1.2.2.1 Design

The B-52 Offensive Avionics System (OAS) was designed by Boeing Military Airplane Company (BMAC) in response to SAC ROC 6-75 with the support and direction from the USAF and DOD as well as information from avionics companies. The OAS system architecture makes use of the MIL-STD-1553A data bus to integrate the pair of AP-101C computers with the controls and display subsystem and the navigation and guidance subsystem, both of which were specified by Boeing Military Airplane Company. In addition, the data bus interfaces with existing B-52 equipment and the weapon control and delivery equipment.

Boeing Military Airplane Company wrote the processor's specification based upon the system requirements such as those dictating non-volatile memory and the nuclear hardness requirements of AFR-122-10. Boeing Military Airplane Company stated that the AP-101C was really a new machine, even though its architecture was based on the 4-Pi family.

Boeing Military Airplane Company stated the original specifications for the OAS ask for capability and flexibility that USAF wasn't willing to pay for once they found out how much it was going to cost. Boeing Military Airplane Company stated that USAF had to delete some requirements and then later wanted them back in.

Boeing Military Airplane Company stated that since the program began in 1978 there had been three changes in SAC personnel, and this resulted in changes in requirements since each person interpreted the requirements differently than their predecessors.

Very few modifications were made to the specifications once IBM was selected as computer contractor. The one modification that Boeing Military Airplane Company could identify was the power interrupt test.

Boeing specified the Quality Assurance (QA) test and burn-in. Boeing Military Airplane Company Systems Engineering established the test requirements, while a separate test organization wrote the individual test plans. Boeing Military Airplane Company wrote an integration test plan based on when they wanted hardware delivered. Boeing Military Airplane Company also developed a compatibility test plan.

A CPU tester was acquired from IBM. Boeing Military Airplane Company used this tester, but did not provide this tester to the USAF. Boeing Military Airplane Company Systems Engineering supplied the operational support equipment. During full-scale development, there was no support equipment. There were also no technical orders. Boeing built test support equipment for the support of the full-scale development (FSD). This equipment, while actually owned by USAF, was retained by Boeing. This is not the equipment used to support the operational system.

The Boeing 479 test set supports the operational AP-101C. The initial 479 test set had no capability to dump the AP-101C memory. The 479 test set now has the capability to dump the memory, but runs self tests once it's turned on and the memory is overwritten.

The built-in test (BIT) software for the AP-101C was written by Boeing Military Airplane Company. The specification was that BIT had to detect 95 percent of the faults, isolate 75 percent of the faults to the LRU, and that there had to be less than a 5 percent false alarm rate.

Boeing has their own list of qualified suppliers. Boeing performs a 100 percent screen on incoming parts. They do not rely upon the Defense Electronics Supply Center (DESC) and the Qualified Parts List (QPL).

Individual equipment is subjected to temperature, altitude vibration, and an electromagnetic compatibility test prior to systems integration.

1.2.2.2 Systems Integration

The B-52 OAS consists of a total of 44 new units, 47 units that were previously on the B-52, and 5 units which were on the B-52 but modified. The integration of the new units is the principal thing that occurs in the Systems Integration Laboratory Test Facilities (SILTF). Prior to implementing the integration according to the integration plan, each box must have completed its compatibility test as well as the cable use tests. The SILTF cables typically aren't the same as those actually used in the aircraft according to Boeing Military Airplane Company. Boeing Military Airplane Company stated that the pre-production hardware is still in the SILTF. These prototypes will not be replaced with production hardware since no money has been allocated by USAF to pay for the replacement system. In the SILTF, Boeing integrated the hardware item by item and simulated the weapon system interfaces and B-52 existing aircraft interfaces with the OAS. The OAS software and hardware were integrated in a sequence as prescribed in the integration plan.

Boeing Military Airplane Company has constantly upgraded the SILTF to emulate the aircraft itself.

Boeing Military Airplane Company performed a reliability burn-in of the pre-production units. They did not find the problems that they subsequently did in the Test, Analyze and Fix (TAF) on the production items. Boeing Military Airplane Company stated that the qualification test purpose is to find out if the design is good. Qualification testing occurs prior to production. Boeing Military Airplane Company personnel do not believe that burn-in helped that much.

Production hardware was being built on the B-52 OAS prior to the start of Full-Scale Development (FSD). During the Full-Scale Development, Boeing performed a Test, Analyze and Fix (TAF). During the TAF, the complete system was never subjected at one time to a complete test due to environmental facility limitations, etc. The individual boxes were tested and a number of subsystems were operated as integrated subsystems. Boeing Military Airplane Company kept records on the time on the LRUs and the cause of the failure. When failures occurred, they fixed the failed item to the original design documents while they analyzed the failure and, in the case of many of the same failures, they initiated a redesign. After another failure, Boeing Military Airplane Company implemented the design change when the design change was ready; otherwise Boeing Military Airplane Company restored/fixed the system to the original system design, and continued testing. The TAF was performed for a total of six months.

Boeing Military Airplane Company stated that TAF isn't to fix a design. TAF is to find and fix production problems. The TAF for the B-52 OAS avionic systems found problems even after FSD was complete.

Boeing Military Airplane Company stated if TAF is done when USAF has Class I Control, they will get something useful. TAF prior to when the USAF has control, leaves the door open for any kind of uncontrolled change. Boeing Military Airplane Company feels that the use of TAF earlier in the system life cycle will not be cost effective.

1.2.2.3 Operation/Maintenance

Boeing Military Airplane Company stated that every Air Force base is different as to how the computer is used. Some bases just reload in-flight in case of a failure. Others take the computer to the shop and then return it to use. The majority of computer failures are transient type failures.

Boeing Military Airplane Company provided information on a design change that has occurred since the OAS was made operational. The first Air

Force base having the OAS had no processor problems. The second Air Force base had no processor problems. The third Air Force base to receive the OAS had all types of processor problems. Each base received later serial numbers of the system. The problems that occurred at the third base were determined to be due to a software change made after deliveries to the first and second bases; and this change affected only systems delivered to the third base. The problem was a "race" condition when data was pulled from the Read Only Memory (ROM). This problem was reported as a parity error. IBM ran their test software and the box tested OK. The Boeing software caused the problem, which was a hardware item, to manifest itself. Boeing isolated the problem, but it actually required a full up system with Boeing software to cause a problem to be manifested. IBM was required to fix the problem, since their hardware was the source of the problem.

Boeing Military Airplane Company stated that the hardware is very reliable. They have had three aborts due to OAS failures in 30,000 flying hours. Software errors are small compared to the number of human operator errors. Boeing Military Airplane Company stated that they have had problems in which the USAF operators tried to load more waypoints than the software was designed to handle. Since the Technical Order did not address this, the USAF operators assumed that they could load as many waypoints as they wished to. Boeing Military Airplane Company proposed that better Technical Orders would reduce human operator errors of this type.

Boeing Military Airplane Company recommended that more time (and money) be devoted to testing. A number of problems which should have been caught early in the development phase were not caught until later because extensive testing was not performed. Boeing Military Airplane Company believes that if USAF wants to have integrity, they must be willing to pay for the testing. Boeing Military Airplane Company stated that the USAF must really decide how much risk they want to take. The Test, Analyze and Fix (TAF) program on the B-52 OAS provided engineering information on the failure modes, mechanisms and rates of a test item under natural and induced environmental conditions of military operations. Boeing Military Airplane Company believes that this resulted in the prevention of the recurrence of failures due to incorporation of corrective action.

1.3 CASE STUDIES CONCLUSIONS

An analysis of the information collected from the two computer manufacturers and two systems integrators resulted in the following findings:

- Computer test equipment that is used by the computer manufacturer, while available to the systems integrator, is generally not used by the systems integrator except at his own facility. The systems integrator provides USAF computer test equipment that is of a different design and either manufactured by the systems integrator or by another subcontractor, but not by the computer manufacturer. This results in problems in duplicating test results when the computer is returned to the computer manufacturer.

- The systems integrator uses little or no software that the computer manufacturer uses or provides to the systems integrator. The systems integrator typically develops the built-in test and fault isolation test software for the system. The only portion of the software provided by the computer manufacturer which may be used by the systems integrator is the computer self-test software.

- The state-of-the-art built-in test/fault isolation hardware and software apparently is not fully utilized by the USAF user. The information available from this state-of-the-art system is not provided to the systems integrator or to the computer manufacturer by the USAF. If state-of-the-art BIT is not currently used, it must be asked if the more sophisticated BIT and FIT will be used.

- USAF does not collect data that would be useful to improve the design of future avionics and the integration of those avionics to the subsystem manufacturers and the systems integrators. The limitations of manual data collection procedures and existing data bases must be removed by the implementation of automated or computer controlled procedures and techniques. These automated or computer controlled systems can be used to collect and feed back the information required by the manufacturers of the subsystems (as well as the system integrators) in a format that is both timely and complete.

- Both the Delco computer and the IBM computer had nearly equivalent predicted mean-time-between-failure-rates. The Delco computer had a predicted MBTF of 2100-2200 hours and the IBM computer had a predicted MTBF of 1800 hours. For the Delco computer the actual mean-time-between-failure (MTBF) was over 2500 hours, whereas the IBM computer had a demonstrated MTBF of 1600 hours. In both cases, however, the mean-time-between-removals (MTBR) was significantly less than the repair or failure rates. The MTBR was 600-700 hours for the Delco computer and was 600-800 hours for the IBM computer. Table II-1.3-1 shows these data.

TABLE II-1.3-1. Comparison of Failure and Removal Rates for the Delco and IBM Computers

	Delco 362f	IBM AP101C
MTBF (Predicted)	2100-2200	1800
MTBF (Demonstrated)	2500	1600
MTBR	600-700	600-800

It can be seen from the data obtained in these studies that:

(a) The manufacturers used more rigorous parts selection criteria than that which was required in order to obtain the "best" parts for use in the avionic system.

(b) In both cases (Delco and IBM), environmental stress screening was used to insure that the infant and latent defects were removed prior to submitting the parts to the manufacturing process. However, it was not used extensively on sub-assemblies or assemblies.

(c) In both cases (Delco and IBM), final acceptance testing was performed at the system level (in environmental chambers) until the units performed failure free for a specified number of hours under thermal cycling and full power.

From these data, it can be inferred that the "good" performance of the field product, in the operational environment, (reference table II-1.3-1) was due to the application of the identified tools and methodologies during the initial design and construction of the system level product.

1.4 CASE STUDY RECOMMENDATIONS

These case studies were primarily directed at the subsystem manufacturer and the systems integrator. It is recommended that the case studies be extended to include a study of the users and each of the maintenance levels for the F-16 avionics system and the B-52 offensive avionics system. Information collected in these extended case studies would be most useful to the USAF in determining needed improvements to the maintenance data collection and distribution procedure. The proper feedback from this improved procedure would result in increased avionics integrity due to the manufacturers' and the systems integrators ability to understand and correct problems in a more timely manner due to the fact they will have been provided the proper information and data in a reliable and complete data base as soon as it occurs or is generated.

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